ALL ABOUT

VLF Active Antennas

Because of poor antenna performance, the low frequencies are, as a rule,neglected by shortwave listeners. This series of articles will show you how you can overcome those problems and hear what you've been missing.The principles we'll discuss can even be used for reception up to 30 MHz.

R.W. BURHANS

GENERAL-COVERAGE COMMUNICATIONS receivers that are capable of continuously tuning from 10 kHz to 30 MHz are becoming ever more popular. However, users are often disappointed with their performance at the extreme low end of the spectrum—but it's not always the receiver that's to blame. Often, poor VLF (*Very Low Frequency*) performance is due to the use of an untuned, random-length antenna. Such antennas are often used because of the difficulty of building a full-size VLF antenna. As, we'll soon see, however, full size antennas, aren't always necessary for good reception at low frequencies.

This series of articles will introduce you to practical active-antenna systems that are physically very short. For example, Fig. 1 shows some experimental wide-band active antennas using whips that are just one-meter long. The casual SWL or VLF-LF listener with an appropriate receiver will get good results using those—provided that appropriate attention is paid to such things as antenna location, interference considerations, circuit construction, and ground systems.

Active antenna basics

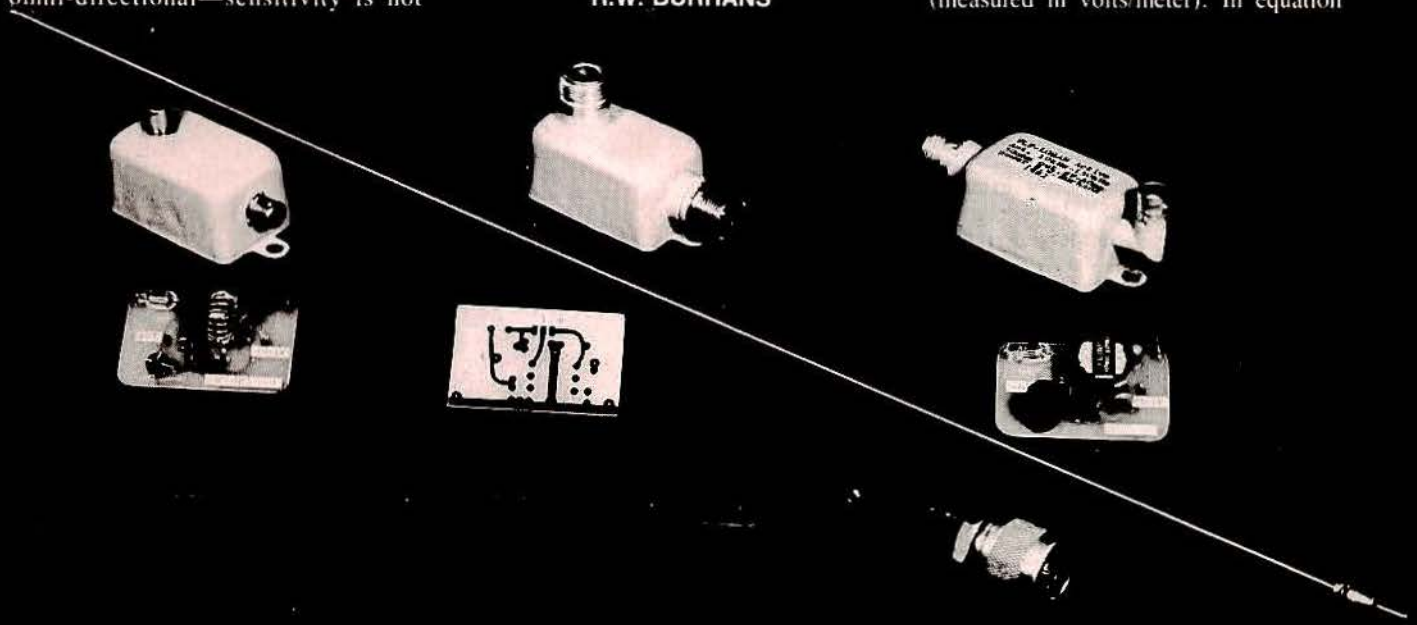
In this discussion, we will restrict ourselves to active systems using vertical whips. Loop antennas are very useful but tuning, coil changing, and an entirely different type of circuitry are needed for that type of active antenna system. Short whips are usually easier to make and operate, but have the disadvantage of being more sensitive to local noise (power-line noise, for example). Loop antennas are directional—they have to be oriented with respect to the signal for best sensitivity. On the other hand, vertical whips are omni-directional—sensitivity is not affected by the antenna's orientation.

Typical active antenna preamplifiers operate primarily as impedance converters or current amplifiers—they convert a small input-signal voltage at a high-impedance input to nearly the same voltage at a low-impedance output. A coaxial cable is connected from the output to the receiver's low-impedance antenna input (typically 50 to 500 ohms). As is common in many TV antenna-mounted preamplifiers, the power for operating the active preamplifier uses that same coaxial cable. There are, however, basic differences between the VLF-HF systems and the TV-type active preamps. For example, the VLF-HF active antenna must have a higher input impedance and more attention must be paid to the details of the amplifier's dynamic range and distortion. Another difference is that the frequency range covered by the VLF-HF preamplifier is a couple of orders of magnitude greater than that covered by the TV-FM units.

Active antenna preamplifiers mounted at the base of a short whip antenna are most often used at low frequencies (10 kHz to 100 kHz). There, the antenna length is much less than .001 wavelength. The general rule in airborne or marine VLF communications, or Omega and Loran-C navigation systems is to use a short active-antenna system .

Antenna sensitivity

Let's now introduce the concept of *effective length* (l_e). (In low-frequency usage, that is sometimes referred to as effective height). The effective length of an antenna is equal to the ratio of the voltage at the antenna output terminals to the field strength of the input signal (measured in volts/meter). In equation



form that is stated as:

$$\frac{V_{OUT}}{E_i} = l_e$$

The ratio of the effective length to the physical length (l) is a measure of the antenna efficiency. For example, an antenna with a physical length of 100 cm could have an effective length of 20 cm. The resulting output signal strength E_o would then be only one fifth that of the input.

The effective-length-per-unit-length of an active antenna can be estimated by determining the input capacitance of the system. That input capacitance includes the antenna-mount capacitance, C_m; the input-wiring capacitance, C_g, and the antenna-whip capacitance, C_a. (See Fig. 2-b.) The relationship is:

$$\frac{l_e}{l} = \frac{C_a}{C_a + C_m + C_g} \quad (1)$$

A typical one-meter long whip antenna might have a measured C_a of about 10 pF over a flat ground plane. Also, an antenna mount might have a fixed capacitance of C_m = 5 pF and the input wiring and active circuit capacitance might be C_g = 8 pf. The efficiency for a system with those values would be:

$$\frac{10}{10 + 5 + 8} K = \frac{10}{23} K = 0.434\ K \quad (2)$$

The factor K (which was assumed to be equal to 1 in equation 1) is a measure of the nearby shielding or coupling effect of the local ground plane (trees, structures, buildings, etc.). In practice, K is always less than one. A value of 0.75 might be obtained with a top-hat capacitive-loaded vertical antenna mounted on a pole or structure such that the local ground plane slopes away from the antenna on all sides. Values of K as low as 0.1 might be possible for a low horizontal wire with trees or buildings close to and higher than it. For example, let's presume that the K of equation 2 was equal to 0.5. The effective length would then be 0.434 × 0.5 = 0.217 meters. That is typical of what is actually observed with a medium-quality active antenna with a length of 1 meter. Another way of thinking about that antenna is to say that its efficiency, in terms of converting the input field strength to a corresponding level at the output terminal, is about 21.7%.

Because of the coupling factor, an active antenna mounted up in the clear will generally outperform an antenna mounted near obstructions. At VLF frequencies, a hill or mountain 0.5 km away from the antenna can reduce the antenna's sensitivity. Precision measurements of the phase and amplitude of 100-kHz Loran-C signals, made while flying over hilly terrain at low altitudes, can yield information about the variations of ground conductivity and terrain contours, which are related to K.

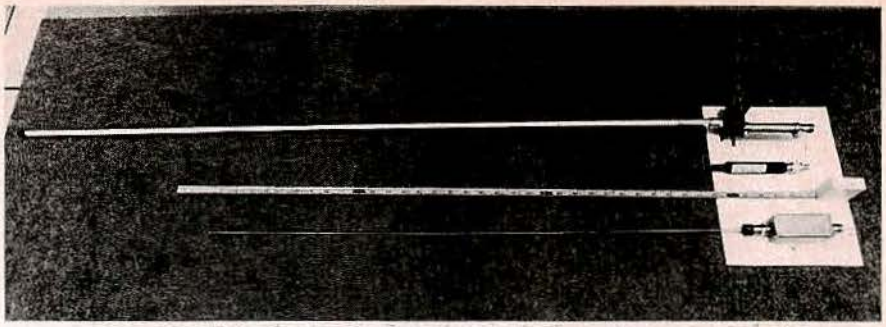


FIG. 1—EXPERIMENTAL WIDE-BAND ACTIVE ANTENNAS. The ones shown here are approximately one meter (39.47 inches) long. The tape measure is pulled out to 41 inches.

Input impedance

Active antenna receiving preamplifiers at frequencies of about 10 kHz have a high input impedance (greater than 1 megohm). That is because of the low antenna capacitance (C_a). Thus, the whip antenna can be considered to be a voltage source with a high internal impedance when coupled to the preamplifier input terminal (see Fig. 2). That internal impedance becomes lower as the frequency of operation is raised—reaching a value around 10,000 ohms at the AM broadcast band (1-MHz region).

If a short whip were connected directly to a 500-ohm receiver input terminal, a LF signal would be greatly attenuated as a result of the mismatch. For example, let's look at what would happen to a 10 kHz signal. The reactance of C_a for a 1-meter whip would be about 1.6 megohms at 10 kHz. Without an active preamplifier, the attenuation would be about 500/$(1.6 \times 10^6 + 500)$ ohms, or roughly −72 dB! If, on the other hand, an active preamplifier were used, the same 1-meter whip would provide ample signal at 10 kHz, as the source would be much more closely matched to the load.

The effective capacitance of a wire antenna is approximately 10 pF/meter. Thus, at 10 kHz, a 30-meter wire antenna directly connected to a 500-ohm receiver-input terminal is a 50,000-ohm reactance. Another way of looking at that is to say that the antenna efficiency is 500/50,000 = .01, or 1%. At 10 kHz, our 21.7%, 1-meter active antenna looks much better than that 30-meter wire.

As we go higher in frequency, up to the 30-MHz region, the impedance of the 1-meter whip decreases to the point where it could be connected directly to a low-impedance receiver input. Hence, active, high-input-impedance antenna systems are most useful at the VLF-LF range (usually below 500 kHz); at those frequencies they can perform as well as a very-long-wire antenna that is connected directly to the receiver's low-impedance input.

Antenna noise levels

In airborne applications, for aerodynamic considerations and to minimize interference, it is desirable to use as small an antenna as possible in the VLF range. A recent FAA report suggests a minimum effective length of about 20 cm when operating at 100 kHz (Loran-C). An active antenna with a 20 cm l_e will provide an output signal level of 20 μV across a 50-ohm receiver input terminal when it is immersed in a 100 μV/meter electric field.

The antenna noise level found in a receiver is a function of the receiver bandwidth. A typical Loran-C reciever might have a noise level of perhaps 1000 μV/m. Thus, a weak Loran-C signal may be buried in noise to the 100 μV/1000 μV, or −20dB S/N level at the antenna input.

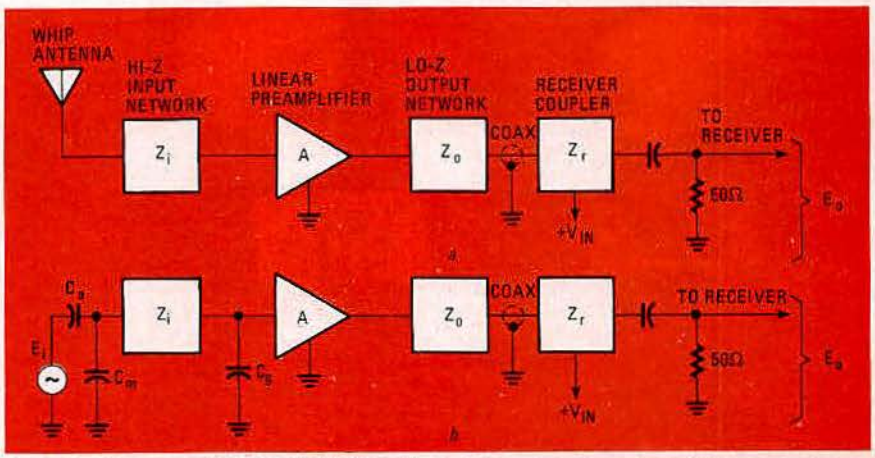


FIG. 2—BLOCK DIAGRAM OF AN ACTIVE ANTENNA is shown in *a*. The whip antenna is replaced by its equivalent circuit in *b*.

even though the total signal and noise level (S + N) is quite high at the preamp output. That is a general characteristic of most VLF-LF receiver systems. The antenna noise is much larger than the receiver-circuit noise levels by at least an order of magnitude.

Figure 3 is a chart that shows the magnitude of the atmospheric noise level (in the midwestern United States at 170 kHz) as a function of the receiver bandwidth. Summer afternoons are dominated by the noise of thundershower spherics. They produce a typical noise level of 100 μV/m (40 dB above 1 μV/m) in a receiver with a 400-Hz bandwidth. In the morning, summer noise levels are lower. Lower still are the winter noise levels, which are usually less than 1 μV/m. However, in the winter, the antenna becomes less sensitive despite the reduced noise level. That is due to the lower conductivity of ice and frozen ground. For example, propagation of VLF signals is very poor over a large ice mass like the Greenland ice cap. The action is similar to that of a carbon wedge inserted into a microwave waveguide.

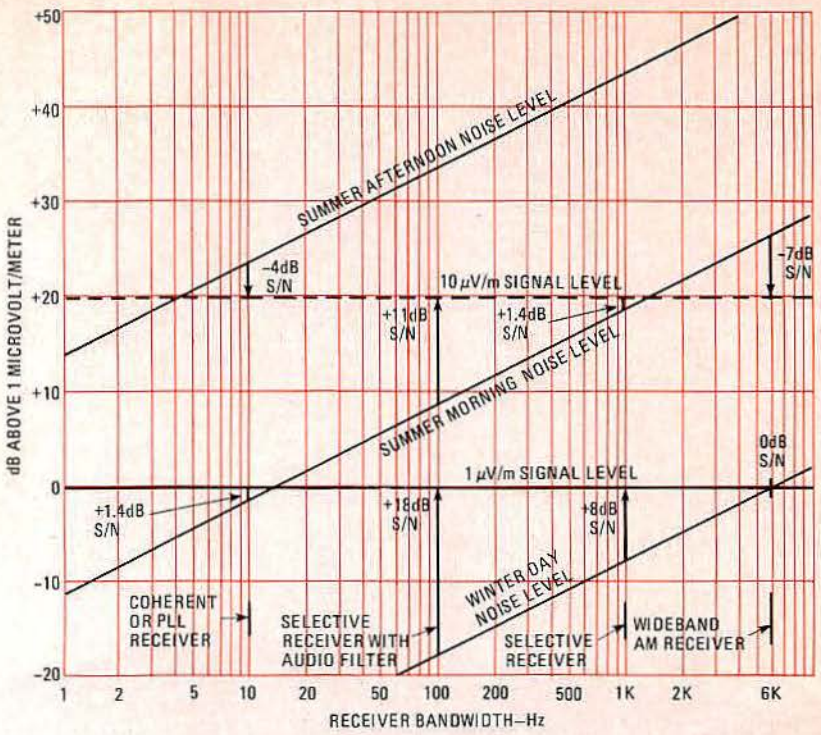


FIG. 3—ANTENNA NOISE LEVELS are a function of the receiver's bandwidth and differ from season to season as well as with the time of day.

Intermodulation distortion

We want an active-antenna system that will ensure that the signal heard on the receiver is not some spurious response of the preamplifier or the receiver itself. That may be rather difficult in some urban areas, where the general RF-"pollution" level is high over the entire VLF through HF spectrum. We do not want our antenna system to amplify strong signals that are in the passband of the active antenna but *not* on the frequency we are interested in receiving.

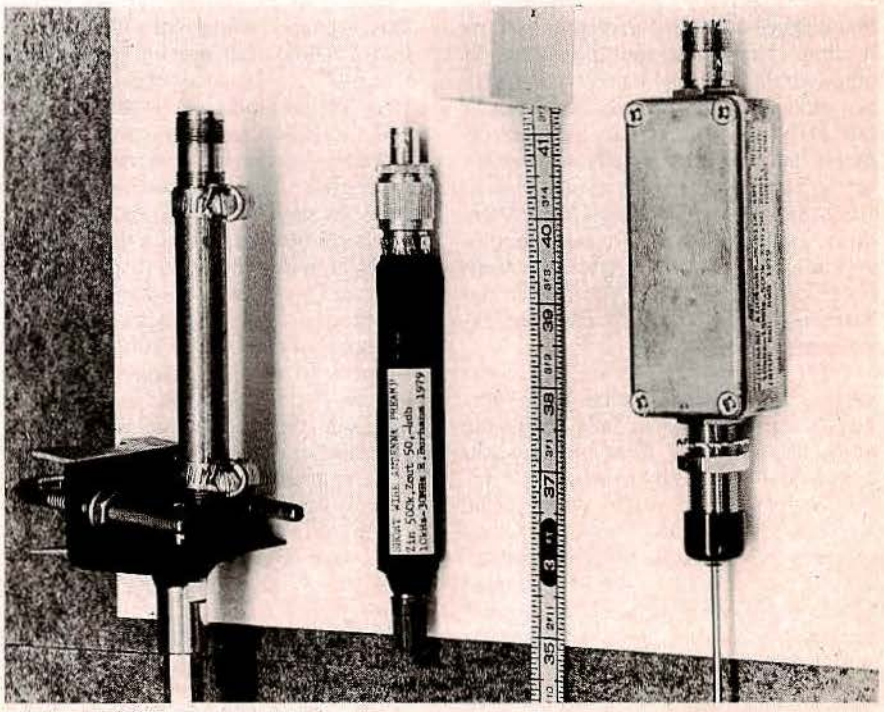
Achieving those goals is difficult in practical wide-range semiconductor preamplifier circuits. That's because they suffer from problems caused by second- and third-order intermodulation distortion products that are created by small non-linearities in the active preamp.

Second order distortion

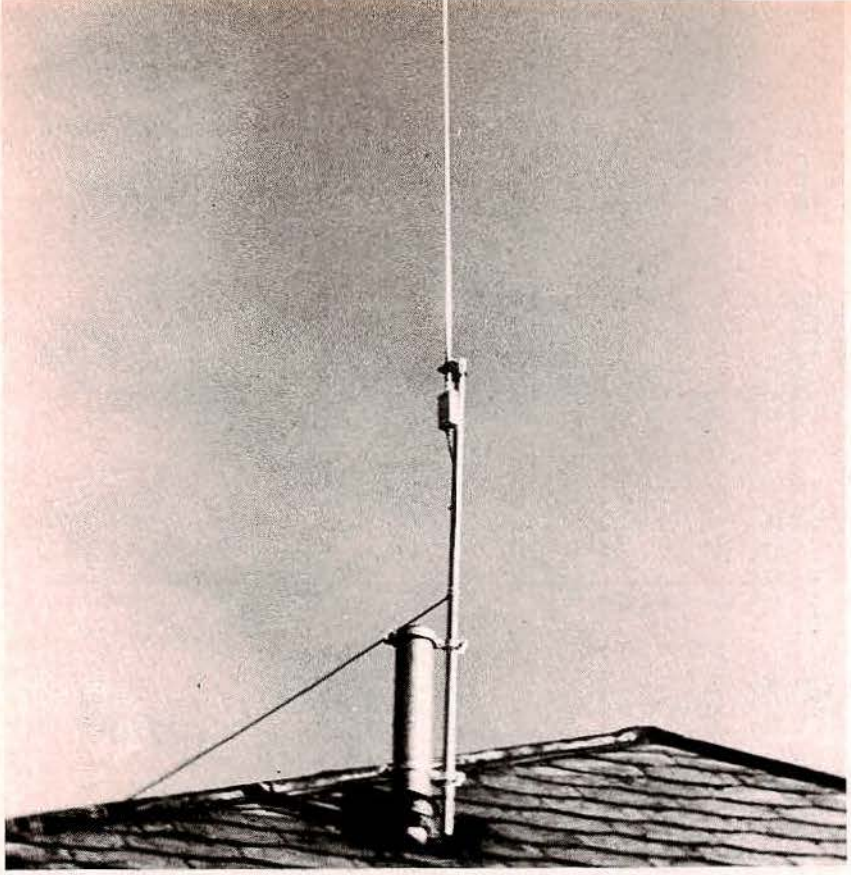
Suppose we have an active-antenna system connected to a receiver tuned to 370 kHz in the LF beacon band. Let's also suppose that there are local broadcast-band transmitters on 1340 kHz and 970 kHz that produce a difference frequency of 1340 − 970 = 370 kHz. If the active-antenna preamplifier is not perfectly linear—and it never is in practice—then at some high signal level, a mixture of the two broadcast-band AM signals will be superimposed on the desired 370-kHz beacon signals. If the listener is located close to the AM transmitters, the interference signal level might be quite high. It increases by 20 dB every time that the strength of the signals causing the interference increases by 10 dB. The problem can be reduced by using semiconductor circuitry that is more linear, or by using high-impedance traps and low-pass filters connected directly to the active-antenna input circuitry.

Third order distortion

Third order distortion can be a more severe problem. It occurs when a strong local AM broadcast-band signal mixes or multiplies with a weaker signal producing interference frequencies of $2f_1 - f_2$ or $2f_2 - f_1$. Suppose f_1 is a weaker signal on 700 kHz and f_2 is a strong local signal on 1340 kHz. Then $2f_1 - f_2 = 60$ kHz and $2f_2 - f_1 = 1980$ kHz. If we tune our receiver to each of those frequencies, signals will be heard faintly in the receiver. The one at 60 kHz is particularly troublesome, since it is right on top of a normal VLF time signal from WWVB and produces annoying fading that coincides with the signal variations from the broadcast stations.



ACTIVE ANTENNA PREAMPLIFIERS can be made very small.



An active-antenna system presents few mounting-problems.

TABLE 1

Harmonic number	Frequency—kHz
1	15.734
2	31.468
3	47.203
4	62.937
5	78.671
6	94.406
7	110.140
8	125.874
9	141.608
10	157.343
11	173.077
12	188.811
13	204.545
14	220.279
15	236.014
16	251.748
17	267.482
18	283.217
19	298.951
20	314.685
21	330.419
22	346.154
23	361.888
24	377.622
25	393.357
26	409.091

That type of two-tone interference increases by 30 dB for every 10 dB increase in the level of the two interference signals. The large number of broadcast-band stations, and the thousands of LF beacons in the continental United States (as well as the world), means that there are many potential interference sources that could cause problems for VLF-LF receiving setups.

Harmonics and overload

Another common type of interference that plagues all types of reception setups is simple harmonic multiplication. In other words, a strong signal on 250 kHz can produce weaker harmonic signals at 500 kHz, 750 kHz, etc. At the VLF-LF range, that problem is usually not as much of a concern as those mentioned above, since the interference caused by second, third, etc. harmonics is usually not as severe as that caused by second or third order distortion. Also, the higher the harmonic number, the weaker the interference signal will be.

Input preamplifier overload can occur when a locally strong station is transmitting at a frequency that falls within the antenna's passband. That problem can sometimes be cured by using traps or input low-pass filters, or by shorting the whip to ground with a remote, weatherproof, low-capacitance relay. However, it is very difficult to get rid of a signal from a nearby amateur or CB transmitter if the active antenna is designed to operate in the same frequency band.

Other interference

Most TV receivers radiate some horizontal-oscillator signal (15.734 kHz); that problem is especially severe in modern solid state and IC sets. The harmonics from that source, up through 400 kHz, can often be heard in a VLF-LF receiver. A list of the TV-oscillator harmonic frequencies up to 409.091 kHz range is shown in Table 1. If your communications receiver lacks a precision digital readout, those interference signals can be used for frequency markers in the VLF-LF range. Sometimes, however, those signals can interfere with the reception of an important beacon. In the case of Loran-C, for instance, the interference from TV harmonics at 94.406 kHz and 110.140 kHz have been reported to disturb the operation of some marine Loran-C receivers near marinas in populated areas; in such situations, audio or notch filters can be used to reduce that problem.

Harmonics from 60-Hz power-line-operated systems can also cause interference. For instance, the 170th harmonic of 60 Hz is 10.200-kHz, which happens to be the Omega navigation-system frequency. That, as you might imagine, can cause problems, especially when an Omega receiver is poorly located with respect to power lines or faulty power-line ground systems. Rusty marine vessels that use 60-Hz power systems have reported problems with those harmonics when operating Omega receivers while at sea.

In some cases, better grounding of house-wiring systems can help reduce interference from power systems. Active antennas work best when some ground reference is provided at the antenna base. That's because any antenna that is very much shorter than one-quarter wavelength acts like an electric field probe that measures the potential difference between itself and its ground plane. Thus, good grounds are always a necessity and they can eliminate many reception problems. As to what type of ground system to use, a cold-water copper-pipe system or deep-driven copper rods and heavy conductors will do; but a large number of copper radial-wires laid out around even a short pole-mounted whip will provide marked improvement in VLF reception.

A wide variety of other types of interference are often heard throughout the VLF-HF region; their sources include garage-door openers, microwave ovens, motor controllers, personal computers, and TV-set remote tuners. The active circuitry contained in such devices often radiates signals at frequencies between 40 and 200 kHz. Many microcomputer systems radiate strong harmonic energy in the 1- to 30-MHz range. Some control systems are vibration-sensitive and can be frequency- and amplitude-modulated by room or household noises. Those signals cause interference that is independent of the type of active or passive antenna used on the receiver.

Active-antenna systems may not be the ultimate answer to a single small receiving antenna covering all frequency ranges, but they can provide very satisfactory performance with proper attention to the details that we've covered in this article. The next article in this series will present some practical circuit details of active-antenna systems for the experimenter, SWL or casual listener. **R-E**

ALL ABOUT

VLF Active Antennas

An active receiving antenna can dramatically improve your receiver's performance, especially at very low frequencies. Here we will discuss some practical circuits for both wideband and narrowband operation.

R.W. BURHANS

Part 2 IN THE FIRST ARTICLE of this series, we presented some of the fundamentals of active receiving antennas. That type of antenna has several advantages over wire antennnas, especially at very-low and low frequencies (VLF and LF). First, active antennas have a short physical length. The active antenna systems that we will discuss here are used with a one-meter long whip. That helps reduce the sensitivity to local noise from sources such as power lines. Because of the active antenna's high input-impedance and low output-impedance, it is more efficient than a simple wire antenna in converting a received signal at the antenna to a corresponding voltage level at the receiver's antenna terminals.

In general, the properties that we want our active receiving antenna to have are: high input-impedance, low input-capacitance, low output-impedance, and minimum distortion/high linearity.

Another objective is to keep the circuit as simple as possible. A single-stage JFET amplifier has the best combination of properties for active antenna preamplifier applications—and it allows the circuit to be kept relatively simple. (This is not to suggest that there might not be better, more complex circuits, using several semiconductors or IC's.)

Wide-band amplifier circuit

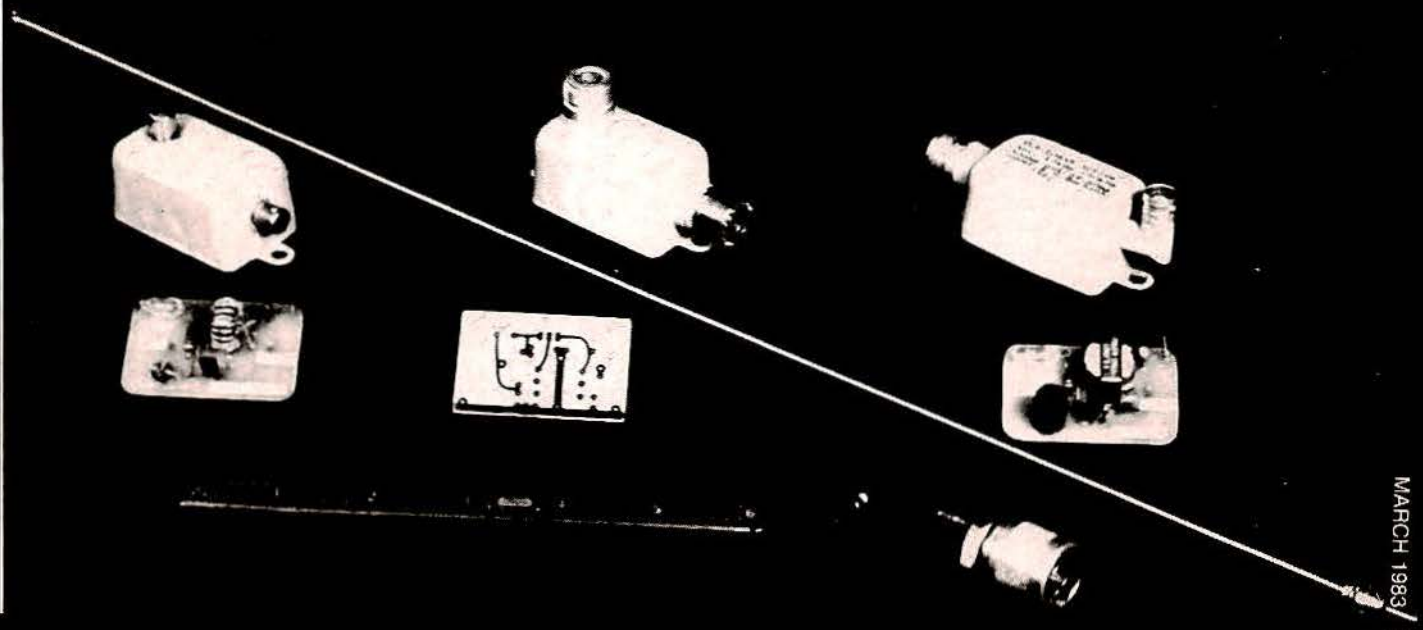
The JFET that we have chosen to use is the Siliconix J-310 (or U-310 in metal can). That JFET is often used as a grounded-gate transmission-line amplifier for TV and FM reception (at a 75-ohm input/output level). The J-310 will usually handle short-duration static surges up to 100 volts or so without damage, so a single low-capacitance neon bulb can provide input static-charge protection. That is of value since semiconductor diodes usually have a much higher junction-capacitance when used as protection devices and, if used, would increase the input capacitance of the preamplifier.

In our application as an active VLF-HF preamplifier, the J-310 is used in a common-source common-drain configuration with inductive feedback (that improves the linearity and lowers the output impedance). Figure 1 shows our wideband circuit for the range of 10 kHz to 30 MHz. Note that the feedback from drain to source is large because of the low resistance of the transformer and its 1:1 turns ratio. (We will discuss how to wind that transformer in Part 3 of this series; that part will contain actual construction details.) For the circuit to operate properly, the transformer's output should be opposite in phase to its input (with respect to ground).

The amplifier circuit is intended to be used with a 1-meter vertical whip. The antenna and its mount capacitances serve as part of an input filter. The input capacitance of the JFET is quite low (about 7 pF). The 2.2-μH inductor at the gate of the JFET serves as a lowpass filter or trap, resonating with the junction and circuit (including antenna) capacitances at a frequency near 30 MHz. That input filter aids in reducing FM-VHF interference over a range of 50 to 500 MHz where the 1-meter whip acts like a resonant antenna.

Receiver coupler

The receiver coupler both provides power to the preamplifier and extracts the signal from the coaxial transmission line (from the preamp). A wideband receiver



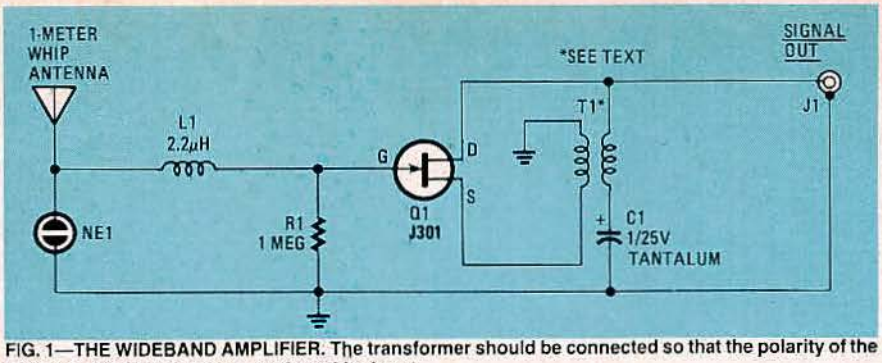


FIG. 1—THE WIDEBAND AMPLIFIER. The transformer should be connected so that the polarity of the output is opposite in phase to that of its input.

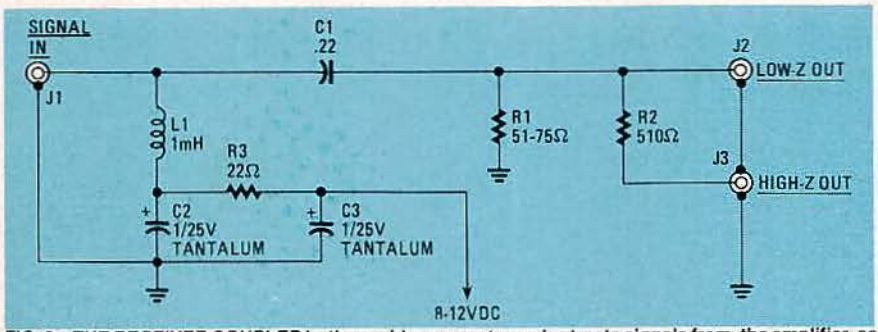


FIG. 2—THE RECEIVER COUPLER both provides power to, and extracts signals from, the amplifier, as well as acting as a highpass filter

coupler is shown in Fig. 2. Capacitor C1 and inductor L1 form a highpass L-section filter (with about a 10-kHz 3-dB rolloff). Resistor R1 is used to ensure that the preamplifier output sees a low-impedance load no matter what sort of receiver is connected. Resistor R2 is used for matching to a receiver with a higher input impedance. That resistor would cause a signal loss of 6 dB if the input impedance to the receiver were 500 ohms.

The coupler circuit provides DC power to the preamp through the coaxial cable. Power sources less than about +8 volts will reduce the dynamic range and linearity of the amplifier. The power dissipation of the JFET using a +8-volt supply will be about 200 mW. The rating of the J310 at 25°C is about 360 mW maximum. In practice, we have not burned one up even when operated with a +12 volt supply for an extended length of time.

The active antenna preamp is like a Class-A amplifier (where the output has low distortion, but the power furnished by the DC power supply is much greater than the power dissipated in the load). However, some distortion does ultimately appear in the output at high input-signal levels. That is due to the fact that a JFET biased in that way cannot be made perfectly linear over a wide dynamic swing of the output voltage. Other modes of operating the JFET with different biasing have been tried, but they have not resulted in any significantly better performance. So, in a sense, the circuits of Figs. 1 and 2 are of the "simpler is better" type.

Intermodulation distortion

A wideband active antenna covering from 10 kHz to 30 MHz has poor performance with regard to IMD (*I*nter*M*odulation *D*istortion) because little input filtering is provided. Interference will be noted especially if the observer is close to strong AM broadcast-band transmitters. The standard method for evaluating the intermodulation response of a receiver is to measure the 2nd and 3rd order intercepts.

Figure 3 shows a plot of the output power of the two fundamental signals (f_1, f_2) versus the output power of the second order and third order distortion products. (We discussed intermodulation distortion products in the first part of this series, which appeared in the February issue of **Radio-Electronics**). Those are shown as a function of the power of a two-tone input signal.

One thing we should mention first is that when the input signals are too large, the amplifier output will not follow the input linearly. That is called *gain compression* and can be seen in Fig. 3.

If the linear portions of the curves are extended, they will eventually cross each other. That is shown in Fig. 3, where the curves are extended by dotted lines and cross at an output level that cannot be reached by the amplifier. The point where they cross is called the *amplifier intercept*. The input and output coordinates where they cross give you the input and the output intercepts.

In general, the higher the intercept point is on the graph, the better the amplifier's capability. Those measurements are best made with a sensitive spectrum analyzer, but an approximate idea can be obtained by using a receiver and recording the S-meter readings with appropriate signal-generator sources. The relatively low number of only +10 dBm for the 3rd order intercept indicates that the active antenna should be used

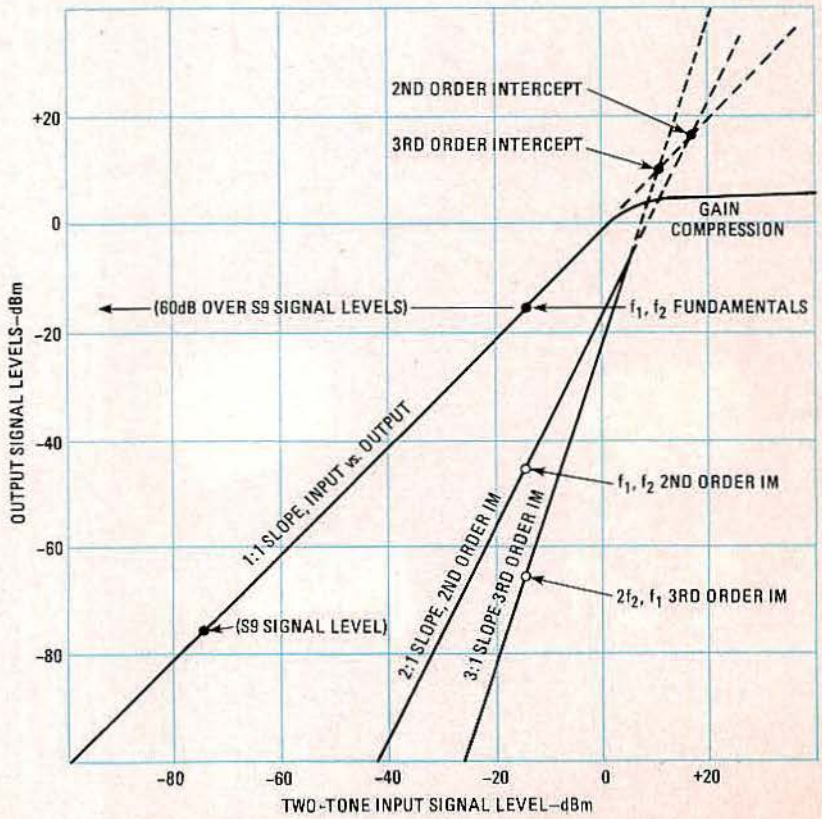


FIG. 3—THE HIGHER THE INTERCEPT POINTS, the better the amplifier's intermodulation rejection.

over a wide frequency range only where the local interference level is not severe. The antenna, of course, might be used in a high-signal area but the observer has to exercise some caution in making sure that the IM signals are not obscuring some desired signals on the same frequency.

For the wideband case of 10 kHz to 30 MHz, those intermodulation-distortion measurements suggest that only a short antenna of perhaps 1 meter or even less will provide the least amount of spurious responses—increasing the antenna length will only tend to increase the distortion level. Longer antennas should be used only when the active preamplifier is provided with some form of input and/or output filtering to reduce the out-of-band interference effects. With added input filtering, an active antenna with a 1-meter whip can provide less IMD because the input filter reduces the likely interfering signals before they have a chance to operate on the preamp input circuitry.

Although the wideband active antenna should not be used with anything longer than a 1-meter whip in areas of high adjacent-channel interference, longer antennas—perhaps up to 10 meters—can be tried in a "quiet" location for operating in the VLF-LF range. However, when using long antennas in the HF region there is an additional interference problem because the antenna is resonant at more than one frequency. One rule to follow here is to keep the length of the antenna less than 1/10 wavelength at the highest frequency used for a wideband system. Although that is short at the highest frequency, an antenna of that length used with the wideband preamp will perform almost as well as a 48-inch top-loaded vertical connected to a 50-ohm system (as in mobile CB radios at the 27-MHz region). A primary reason for using an active-antenna system is to provide good performance over a wide range with small physical size. Thus, if the antenna is to be used only for the CB range, it would be simpler to use an ordinary CB antenna and avoid all of the wideband problems.

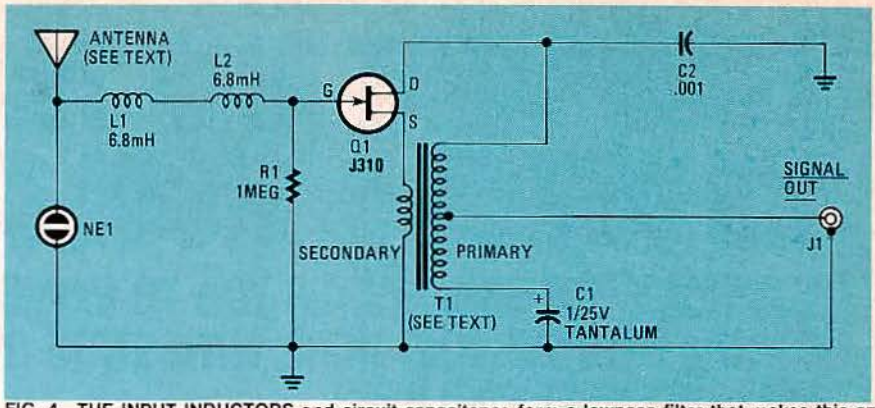


FIG. 4—THE INPUT INDUCTORS and circuit capacitance form a lowpass filter that makes this an amplifier for restricted use in the VLF-LF range.

Amplifier circuit—VLF and LF

At frequencies below about 500 kHz, the amplifier circuit is modified to provide input filtering and higher voltage-gain. Figure 4 shows the modified circuit. Two input inductors and the circuit capacitances form a lowpass filter with a cutoff frequency near 450 kHz (see Fig. 5-a). The choice of those inductors is somewhat critical because the preamp's operation depends partly on the resonant frequency of the coils, the distributed capacitance, and the capacitance of the windings to the shield housing. To reduce mutual coupling, the coils are connected in series with their windings opposing each other. Therefore, they still can be mounted close together on a small circuit board with no interstage shield. That arrangement provides at least another 30 dB of attenuation for broadcast-band signals directly at the input to the preamplifier where the problem of intermodulation starts. A single inductor can be used, but it will not provide quite as sharp a cutoff for interference from the AM broadcast band.

The output transformer is an ultra-miniature audio-output transformer with a 200-ohm center-tapped primary and an 8-ohm center-tapped secondary. (We will talk more about that transformer when the series continues.) The output transformer has good response to at least 400 kHz, even though it was originally intended for audio-frequency use. The smaller amount of feedback applied from drain-to-source results in higher voltage gain of about +6 dB at the expense of slightly less power gain, or a higher output impedance when compared to the 1:1 wideband toroid. However, we use the iron core transformer because of its low cost as well as the lowpass output filtering provided.

When used with a 1-meter whip, the VLF-LF version of the active antenna—with an input lowpass filter with about a 450 KHz rolloff—provides higher intercept points with respect to broadcast-band interference (although it is about the same for interference from other frequencies). If you are located in a region free from high-power broadcast-band transmitters, then you can use the preamplifier of Fig. 4 with longer antennas. However, a point is reached with any active system where merely increasing the antenna size does not improve the overall signal-to-noise ratio because the atmospheric noise level increases at the same rate as the signal.

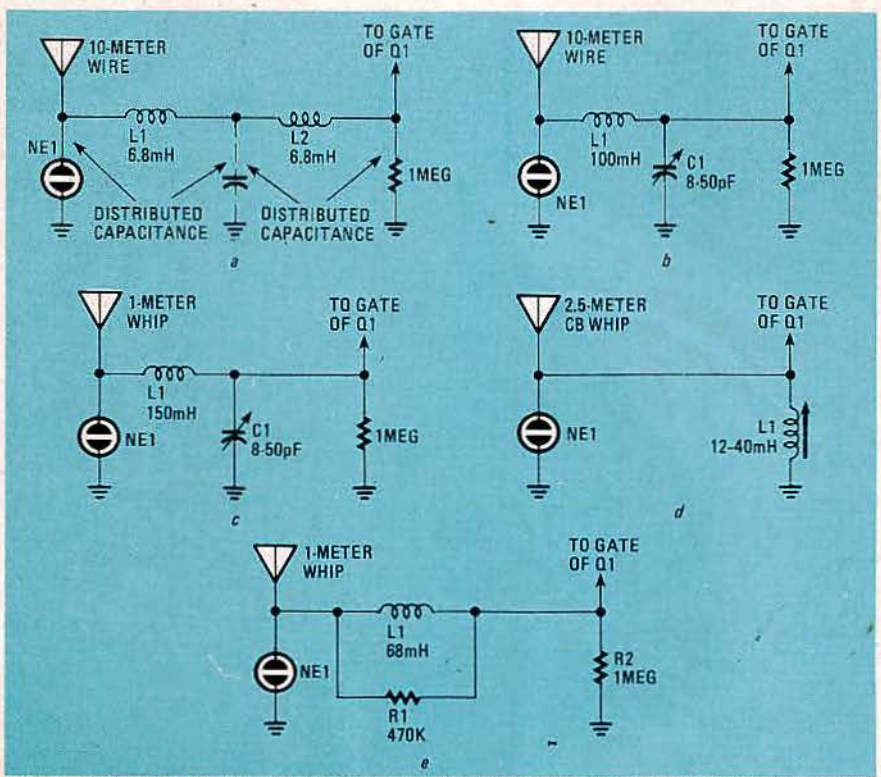


FIG. 5—VARIOUS INPUT NETWORKS for VLF-LF operation can improve performance at particular frequencies or increase the antenna's selectivity.

Resonant input circuit

Figure 5 illustrates various high-impedance input networks for restricted use in the VLF-LF region (such as Loran-C only, or WWVB, or for the 160 kHz–190 kHz experimenters' license-free band). A series inductor with a small input tuning capacitor can be used to further reduce interference and increase the antenna performance. A miniature trimmer-capacitor with a tuning range of 8 to 50 pf placed from the gate to ground, directly across the 1 megohm input resistor (see Figs. 5-b and 5-c) provides a means of tuning the series inductor for a peak at the desired frequency range. The result is a sharp, high-frequency cutoff with a more gradual low-frequency rolloff. The inductor was chosen to be self-resonant (remember, real inductors also have capacitance) at a somewhat higher frequency than the top of the desired tuning range. That technique will work for some pot-core or slug-wound inductors but will usually not work well with large toroids, as they have too much distributed capacitance at VLF. It is also possible to shunt a slug-tuned inductor from the gate to ground (as in Fig. 5-c) but the preamp will then require a larger housing. For that parallel-tuned case, the 1-megohm resistor can be removed because the inductor provides the ground return for the gate. The antenna is then connected directly to the gate terminal with the inductor chosen to resonate with the antenna, input-circuit, and antenna-mount capacitances. The minimum of external tuning capacitance provides the highest Q (most selective) antenna in this application. For DX hunting in the low-frequency experimenters' band (at 180 kHz), a narrowband antenna with a Q of more than 50 can be achieved with a parallel-tuned circuit.

One problem with using a tuned circuit is that it restricts the remote applications of the active antenna. That is because the antenna must be located conveniently so that it can be retuned. However, for covering some fixed frequency (such as the experimenters' band) the antenna system can be aligned on the bench and then mounted for unattended operation. When tuning those systems, it is advisable to temporarily mount the preamplifier assembly in a fairly clear area (preferably where it will be permanently located) to avoid nearby capacitive coupling, which might detune a very selective system.

One technique for broadbanding a tuned circuit is to place a resistor in parallel with the inductor (See Fig. 5-d). Resistor values in the range of 50K to 500K ohms can help broaden Loran-C systems where a wide bandwidth is necessary.

Traps

Series-connected transmission-line traps tuned to local broadcast-band stations and placed just ahead of the receiver coupler can improve the IMD somewhat and reduce overload or gain-compression problems (see Fig. 6). The tuning capacitors must be isolated from ground and the inductor must be chosen so as to have a reactance greater than 50 ohms at the desired notch frequency. Dual traps are possible. For example, Fig. 6 shows a trap for 970 kHz and another for 1340 kHz connected in series. The combination of input lowpass filters at the antenna and traps at the preamp output can usually provide sufficient attenuation for cases of severe interference in the VLF-LF band from stations in the broadcast band.

A summary of some measurements made with different antennas at 60 kHz for WWVB reception is shown in Table 1. It should be noted that a 2-meter vertical whip is about equivalent in sensitivity to the much larger flat-top antenna. However, the flat top is much more susceptible to noise and interference, even when it is operated with a lowpass filter at the preamp input. The effective-height estimate may not be the same over the entire frequency range. For example, the flat top appears to have an effective height of about 2 meters at 200 kHz but less than 0.9 meters at 60 kHz. That is because of

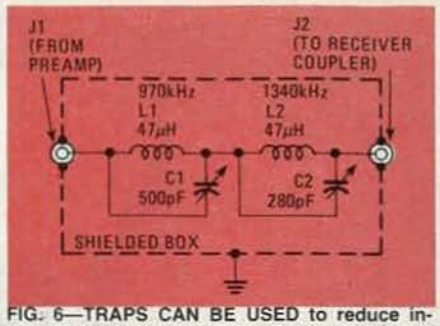


FIG. 6—TRAPS CAN BE USED to reduce interference from broadcast band stations—in this case from stations at 970 and 1340 kHz.

K—the shielding effect and conductivity of the local ground terrain, which includes all the trees, power lines, and building structures. However, we are still able to operate the antenna even down to the 10.2 kHz Omega frequency with reasonable success and it is used routinely to check GBR on 16 kHz for VLF propagation conditions. (GBR is a high-power military VLF station from Great Britain.) In practice, it is always wise to check for IM effects at the specific frequency range that you plan to use the antenna. Sometimes they are severe but only at relatively narrow frequency ranges usually not in the VLF range.

For general wideband surveillance, the 1-meter whip with an effective height of about 30 cm is the best antenna of all, because it has fewer IM interference effects and less local noise from the power lines.

A general conclusion from all of the experiments is that the local environment and the ground-conductivity effects of nearby structures are the most important factors in determining antenna sensitivity. Small changes in antenna location can produce remarkable differences in the antenna's performance.

Another observation is that the best location for a short whip is invariably up high in the clear. (That can especially be seen in aircraft applications where a very short vertical whip is used with remarkably good performance.)

Low-frequency experimental radio station operators have reported good results in mobile operation with reception of 160 to 190 kHz signals using 2.5-meter CB whips and parallel-tuned input networks. We have conducted similar experiments with Omega and Loran-C receivers in mobile vehicles where the only problems were those of shielding from buildings or when driving under bridges or near power lines. An additional problem in mobile operations is harmonic radiation from the vehicle's AC alternators.

When we continue this series, we will discuss construction details and include printed-circuit board layouts for the active antenna preamplifier and receiver coupler. We will also discuss how to bench test the preamp, and how to mount the system. **R-E**

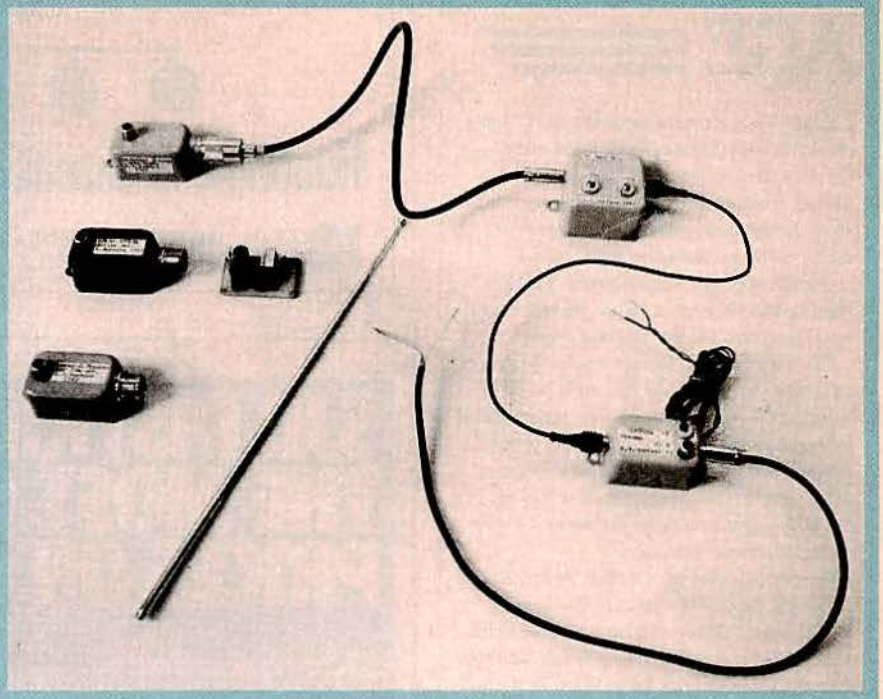
TABLE 1

Parameter		Whip 1	Whip 2	Flat Top
Physical Height	(h_m)	1m	2m	10m
Antenna Capacitance	(C_a)	10pF	20pF	118pF
Fixed Capacitance	($C_m + C_g$)	15pF	15pF	15pF
Voltage Gain at Preamp	(A_v)	1 (0dB)	1 (0dB)	2 (+6dB)
Estimated Ground Coupling Effect	(K)	0.7	0.7	0.05
Effective Height	(h_e)	0.28m	0.80m	0.88m
WWVB Reading on YAESU FRG-7700		S6	S9	S9+
Estimated E-field for WWVB (from NBS chart)	(E_i)	150 μV-per-m	150 μV-per-m	150 μV-per-m
Output S+N for ($E_o = E_i \times h_e$) 60kHz WWVB at Preamp		42 μV	120 μV	132 μV
Estimated (S+N)/N during 60 Hz "quiet hours"		+10dB	+20dB	+20dB
Overall Noise Rating		good	fair	poor
IM Distortion Rating		fair	poor	very poor

VLF-HF Active Antennas

Active receiving antennas can offer a surprising improvement in the capabilities of your receiver. However, as we will show you, building one does not have to be difficult.

R.W. BURHANS



Part 3 IN THE PREVIOUS TWO parts of this series on VLF-HF receiving techniques, we covered both the fundamentals of active receiving antennas and some practical circuits. Now we are ready to discuss the actual construction of those antennas.

The active-antenna system consists of three main parts: a whip antenna, a preamplifier, and a receiver coupler. The whip antenna is directly attached to the preamplifier, and both are remotely mounted. The receiver coupler is mounted at the receiver, and is connected to the preamplifier by a length of coaxial cable. Let's now take a look at the components of the system in more detail.

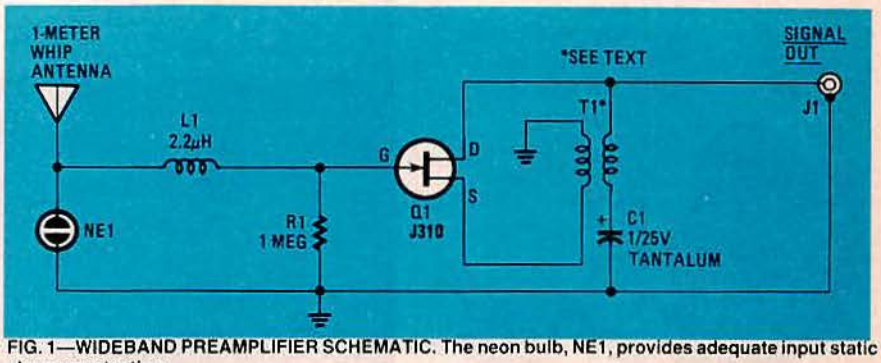


FIG. 1—WIDEBAND PREAMPLIFIER SCHEMATIC. The neon bulb, NE1, provides adequate input static charge protection.

Wideband preamplifier

The wideband preamplifier circuit was discussed in the March 1983 issue of **Radio-Electronics.** Its schematic is reproduced in Fig. 1.

The wideband preamplifier is assembled on a printed-circuit board. The foil pattern of that PC board is shown in Fig. 2, and its parts-placement diagram is shown in Fig. 3. You should note that there are some "extra" pads near the input terminal. They are there to accommodate different input filter networks and/or variations in the size of the components used. The board is intended to fit snugly in a 1¼ × 2 × 1 inch drawn-steel case, although it can be used, of course, with a larger box. The only "fussy" component is the toroidal transformer.

The toroidal transformer is wound by first measuring out two 15-inch lengths of different-colored, 30 gauge, solid, insulated, wire-wrap wire. Those wires are twisted together about 8 turns-per-inch, and then that cable made up of the twisted pair of wires is wound for 17 turns on an Amidon (12033 Ostego St., North Hollywood, CA 91607) part No. FT50-75 (or similar) ferrite core. The windings should be tight, with a small gap at the start/finish point. The wire is held in place at the ends with a small drop of cement, and about 1 inch is left for connection to the circuit board. The insulation at the ends of the wires is stripped back about ½ inch for soldering to the board.

One important note is that the windings should oppose each other. What that means, is that while one wire at one end of the two-wire cable is connected to ground, the other wire at the same end is connected to the drain of the JFET. To furthur clarify that, Fig. 3 shows a dot at the one end of each winding—the dots are at a common end of the cable.

After the transformer wires are connected through the circuit-board holes, the core assembly should be cemented to the board perpendicularly. Be sure to follow Fig. 3 and make sure that the necessary jumper wires are also connected on the board for the wideband version (a version of the preamp for restricted VLF and LF use uses the same circuit board, but some different components).

The lower 3-dB point (where the response of the preamp drops 3 dB from its maximum) is at 10 kHz, where the toroidal transformer has an inductance of about 1 mH. At high frequencies, the core material effectively disappears, and the

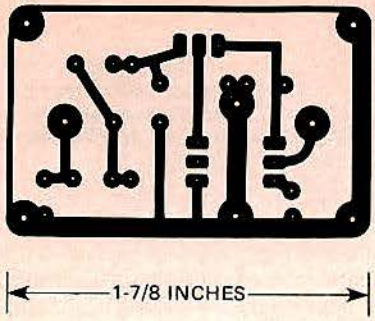


FIG. 2—FULL SIZE foil pattern for the the preamplifier circuit-board.

PARTS LIST
WIDEBAND ANTENNA PREAMP

R1—1 megohm, ¼ watt
C1—1 μF, 25 volts, tantalum
Q1—J310 FET (Siliconix or equivalent)
NE1—NE99 neon lamp
L1—2.2 μH (Mouser 43LS226 or equivalent)
T1—Bifilar wound transformer on Amidon FT50-75 core or equivalent (see text)
Miscellaneous:PC board, case, coaxial connectors, hardware, etc.

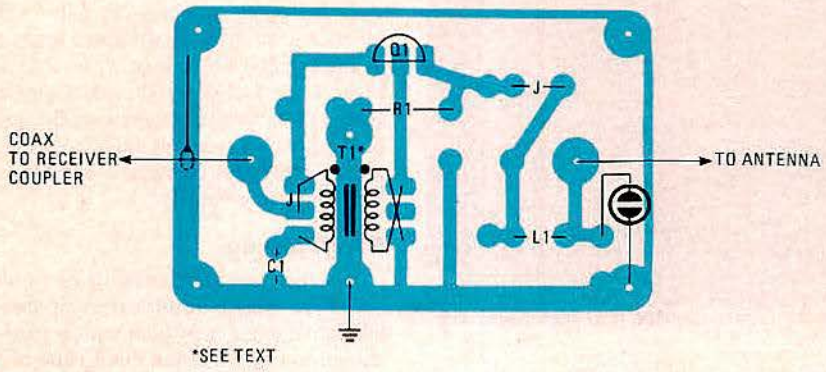


FIG. 3—PARTS-PLACEMENT DIAGRAM for the wideband version of the preamp.

response might be good to 100 MHz or so. However, the 2.2 μH input inductor (L1)—along with the board, the JFET capacitance, and the steel case—limits the preamp's upper 3-dB point to about 30 MHz. That helps to reduce interference from signals outside the desired band—say, TV and FM signals.

The receiver coupler

The foil pattern of the receiver-coupler board is shown in Fig. 4. (The receiver-coupler circuit was discussed in Part 2 of this series, in the March 1983 issue of **Radio-Electronics**. The schematic of the receiver coupler is reproduced here in Fig. 5). The board's parts placement is shown in Fig. 6. The board for the receiver coupler is the same size as that used in the preamp, and can be mounted in a similar case, if desired. In addition to the coaxial input and output terminals, a twisted pair of insulated wires are included for the power-supply leads (8–12 volts) and are fed through a small grommet or hole in the receiver-coupler case.

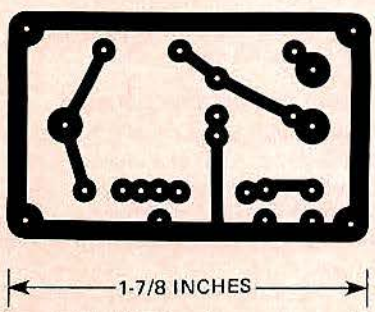


FIG. 4—FULL SIZE foil pattern for the receiver-coupler circuit-board.

We will not discuss the construction of a power supply.

Preamplifier for VLF-LF

The circuit for the VLF-LF preamplifier was discussed in Part 2 of this series, in the March 1983 issue of **Radio-Electronics.** For your convenience, we have reproduced the schematic of that circuit in Fig. 7.

The circuit board for restricted VLF-LF operation is the same as the one used for the wideband preamp. (of course some components are different, and the jumpers that were used in the wideband case are not used here.) The parts-placement diagram is shown in Fig. 8. The RF chokes are short, encapasulated types that are designed for vertical PC-board mounting. The winding "polarity" or the start of the windings are indicated in Fig. 8 by black dots and on the choke package by a label dot and a longer lead.

The output transformer that we chose will fit exactly into the holes indicated, with the correct winding polarity already provided. Therefore—unlike the toroidal transfomer—it is unnecessary to cross over the transformer leads.

If you are in doubt about which side of the transformer is the primary or secondary, check with an ohmmeter. The higher resistance reading (around 20 ohms) will be the primary winding.

Preamplifier variations

In Part 2, we discussed several different resonant input circuits that could be used to provide low-frequency cutoffs, or to yield operation at a small, fixed band of frequencies. (The input networks were discussed in the "Resonant input circuits" section of Part 2.) The preamplifier can be modified with one of these input networks with relative ease. For example, a microminiature trimmer-capacitor can be soldered on the foil side of the board, directly across the 1-megohm input resistor (R1) after the board is mounted in the box. One possible source for the inductors and capacitors is Mouser Electronics (11433 Woodside

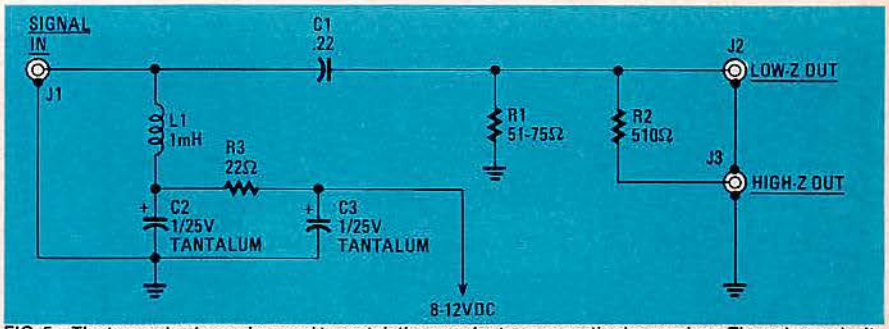


FIG. 5—The two outputs can be used to match the coupler to your particular receiver. They also make it easy to use the coupler with a receiver and monitor the coupler output with a scope at the same time.

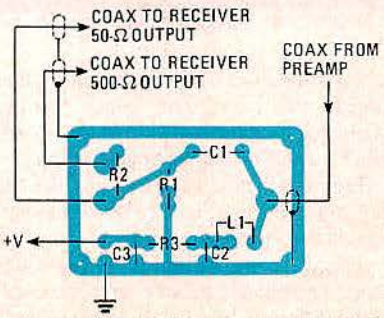


FIG. 6—PARTS-PLACEMENT DIAGRAM for the receiver-coupler board.

PARTS LIST
VLF–LF ANTENNA PREAMP

R1—1 megohm, ¼ watt
C1—1 μF, 25 volts, tantalum
C2—0.001 μF, ceramic
Q1—J310 FET (Siliconix or equivalent)
NE1—NE99 neon lamp
L1, L2—6.8 mH (Mouser 43LH268 or equivalent)
T1—Audio transformer (Mouser 42TL004 or equivalent)
Miscellaneous:PC board, case, coaxial connectors, hardware, etc.

TABLE 1

Frequency/Application	3-dB Bandwidth	Antenna length	C_a	L	C2	Gain
180 kHz Experimenters' Band	170–190 kHz	10 meters	120 pF	33 mH	.001	+20 dB
180 kHz Experimenters' Band	175–185 kHz	1 meter	10 pF	39 mH	.001	+15 dB
100 kHz LORAN-C	95–105 kHz	1 meter	10 pF	120 mH	.01	+6 dB
100 kHz LORAN-C	91–108 kHz	10 meters	120 pF	100 mH	.01	+12 dB
60 kHz WWVB	55–65 kHz	10 meters	120 pF	150 mH	.01	+10 dB
60 kHz WWVB	58–63 kHz	1 meter	10 pF	300 mH	.01	+6 dB

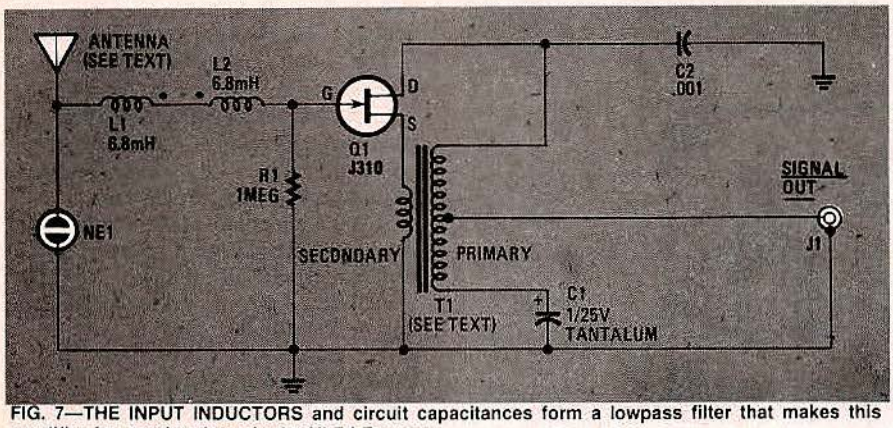


FIG. 7—THE INPUT INDUCTORS and circuit capacitances form a lowpass filter that makes this amplifier for restricted use in the VLF-LF range.

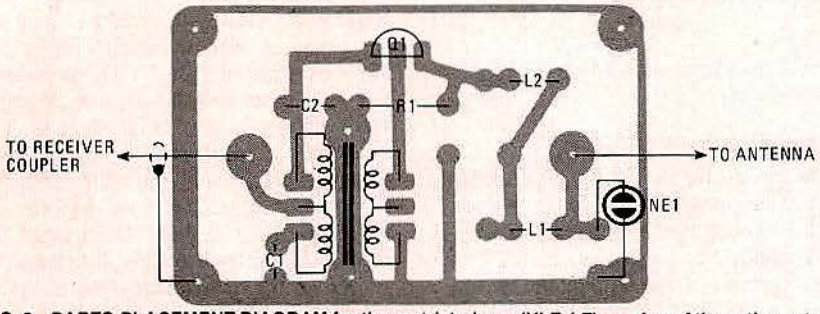


FIG. 8—PARTS-PLACEMENT DIAGRAM for the restricted-use (VLF–LF) version of the active antenna preamp.

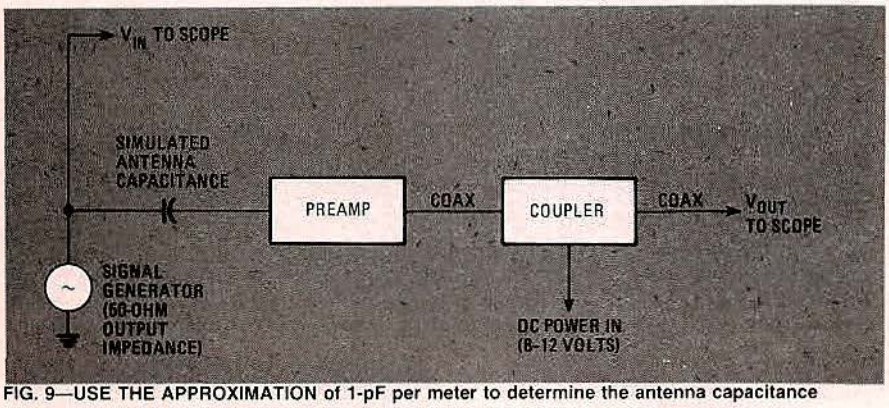


FIG. 9—USE THE APPROXIMATION of 1-pF per meter to determine the antenna capacitance

Ave., Santee, CA 92071), although other suppliers can be found by checking the ads in the back of this magazine.

You may have to bend the leads or change the part orientation if a particular component will not exactly fit the board holes. If you use 100–150-mH RF chokes (for a tuned amplifier for 60-kHz to 100-kHz operation), they will be quite close to the board edges because of their larger size. That will alter the circuit capacitance somewhat when the board is placed inside the box. The small trimmer capacitor—on the foil side of the board—can be used to compensate for that.

For wideband, lower-Q circuits with no trim capacitor, it may be necessary to check the response of the preamp after temporarily mounting it in the shield/case. The board can, of course, be used in a much larger box, with larger inductor assemblies, but keep in mind that for maximum antenna sensitivity with a minimum antenna height (in other words, for maximum efficiency), the input capacitance at the antenna terminal should be as low as possible.

Table 1 shows the results of tests made with different inductor-capacitor combinations for covering different segments of the 60–200 kHz range. (See Part 2—Figs. 1, 4, and 5 for the particular circuits.) Note that in some cases the value of the preamp's output capacitor (C2) at the drain of Q1 is changed to improve the low-frequency cutoff.

For information on availability (including custom-built active-antenna preamps and coupler assemblies), send a SASE to R. W. Burhans, 161 Grosvenor St., Athens, Ohio 45701

Bench testing

A signal generator and suitable oscilloscope are used to observe the response of the active antenna system with a setup as shown in Fig. 9. When tuning any of the amplifier variations on the bench, or when checking the response of the amplifier, a small coupling capacitor—of a value equal to the expected antenna capacitance—is connected to the input terminal of the preamp. (A vertical or slant-wire antenna will have an approximate capacitance of about 10 pF-per-meter.) That will roughly simulate the response of the electric field at the antenna. A tuned preamp assembly can be aligned on the bench and then the antenna can be plugged in for operation. The input/output response obtained this way will fairly-well resemble the response that you will obtain in the field—except for the K factor that is dependant on the local ground-shielding effect.

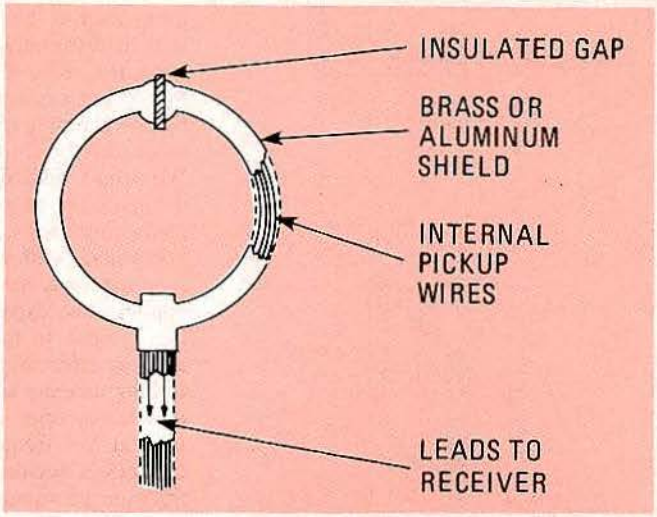
PARTS LIST
RECEIVER COUPLER

All resistors are ¼ watt, 5% unless otherwise specified
R1—51 ohms
R2—510 ohms
R3—22 ohms
C1—0.22 μF, Mylar
C2, C3—1 μF, 25 volts, tantalum
L1—1 mH (Mouser 43LR103 or equivalent)

Preamp and coupler housing

The amplifier and coupler boards have been designed to fit in a small cast aluminium or drawn-steel case such as Mouser part No. 537-M12 for compact assembly. (See Fig. 10.) The circuit boards are held in place in the boxes by short, solid jumper wires that are soldered to the antenna input terminal and to the coax receptacles. The ground connections can be

LOOP ANTENNAS FOR VLF-LF



A discussion of low-frequency reception would not be complete without mentioning loop antennas—the subject of this article.

R.W. BURHANS

Part 5 IN PARTS 1, 2, 3, AND 4 of this series (in the February through May issues of **Radio-Electronics**), we covered several aspects of low-frequency receiving techniques, including the design and construction of an active-antenna system using a vertical whip. This time we'll discuss a different type of antenna—the loop. While this isn't exactly a construction-type article, the ambitious reader will find that he can make his own loop-antenna system using the information presented.

Perhaps the most important difference between loop antennas and the whip antennas that we have previously discussed is the loop's directivity. (The vertical whip is, of course, omnidirectional and cannot indicate the direction from which a received wave comes.) Before we can talk more about this directive property, we have to take a look at how an electrical signal is induced in the loop by a passing electromagnetic wave, and at some general electrical characteristics of loop antennas.

Loop-antenna characteristics

A current is set up in a loop antenna by a changing magnetic field. (That current is equal to the integral of the electric field that is induced around the loop.) The sensitivity of a loop is directly proportional to the loop area and to the number of turns in the loop. It is, in general, inversely proportional to the wavelength of the signal. Small receiving loops for 60 kHz (WWVB) require a preamplifier with a voltage gain of 30 dB or more to make them comparable in performance to a small active whip-antenna.

The inductance of the loop winding itself makes loop antennas frequency-sensitive. Because of that, it becomes difficult to make such antennas with wide-band characteristics. To increase the sensitivity of a loop, multiple-turn coils are used at the VLF–LF range. However, the distributed capacitance of the windings acts with the loop's inductance to decrease the antenna's frequency response. That, however, is not always a disadvantage. The frequency selectivity of a loop winding is often an advantage in that it can provide for rejection of out-of-band signals (in other words, it can form a sharply tunable antenna-system). Loop-antenna systems seldom have intermodulation-distortion problems because of their lower sensitivity, lower impedance level, and better selectivity.

Directivity of loops

Perhaps the most significant and valuable property of loop antennas is the fact that they can be used to determine the direction of an arriving signal. Let's look at how they can do that. Consider a loop and a vertically polarized passing electromagnetic wave as shown in Fig. 1-a. A voltage will be induced in the vertical members of the loop, but none in the horizontal ones. If the voltages induced in each vertical member are the same (as they would be if the plane of the loop were perpendicular to the direction of travel, Z, as shown), then no current will flow. However, if the plane of the loop is parallel to the direction of travel of

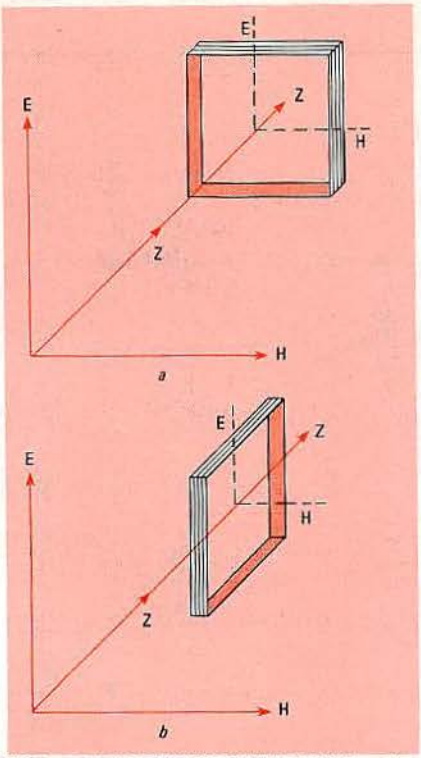


FIG. 1—AN ELECTROMAGNETIC WAVE can be described by its electric component (E), magnetic component (H), and direction of travel (Z).

the oncoming wave, as shown in Fig. 1-b, then the wave will reach one side of the loop before the other, the total voltage around the loop will not be zero, and current will flow. The voltage induced in the vertical members is proportional to the height of the loop, and the voltage difference between the vertical members is proportional to the width of the loop. Therefore, the voltage around the entire loop is proportional to the product of its height and the width—that is, its area.

Another way of reaching the same conclusion is to say that the voltage induced around the loop is proportional to the rate of change of the magnetic-flux linkages through the loop. Then it is obvious that the area of the loop is the controlling factor, and the loop will receive the most signal when its plane is normal (perpendicular) to the magnetic field (H) of the oncoming wave (or in the same plane as the direction of travel of the oncoming wave).

Direction-finding shortcomings

The directional properties of loop antennas that we have just described permit you to null out interference or to obtain a broad peaking of a signal merely by rotating the loop. However, loops, though they are often used because of their relative simplicity, are not ideal direction-finding antennas.

Loops cannot distinguish between signals that arrive from opposite directions (for example, north and south). Another drawback is that trying to determine the source of a signal that arrives at an angle different from that of the ground wave (not exactly head-on) will usually result in an error. Ground waves themselves frequently arrive "tilted." That tilting is often due to the magnetic effects of such things as the steel I-beams of buildings (which distort the boundary conditions even for close-in ground-wave reception). One way that the problems caused by downcoming ("tilted") waves can be reduced is by using an *Adcock* antenna. We won't discuss that antenna in any detail except to say that it operates by cancelling out voltages induced in its horizontal members. A third problem that loop antennas have in direction-finding applications, especially at low frequencies, is due to the *antenna effect*. The antenna effect is seen when a direction-finding antenna acts like a simple, non-directional one. Loop antennas, when used at low frequencies, are subject to that effect because their size is only a fraction of a wavelength, and they pick up interference from a signal derived from the electric, rather than the magnetic, field. A loop's symmetry should ideally cause that signal to be cancelled out, but in real systems the effect is often the source of problems.

Resolving those problems

If you were to turn a loop antenna through 360° and observe the strength of the signal received, you would obtain a reception pattern that looked like a figure-8. Such a pattern leaves you with a 180° uncertainty as to which direction the signal is from. That uncertainty can be resolved by using a whip antenna in conjunction with the loop to cancel one of the lobes of the figure-8 pattern. That is done by coupling the output of the vertical antenna to the loop so that the voltage induced in the loop by the coupling is 90° out of phase with the voltage the passing wave induces in the vertical antenna. Figure 2 shows the cardiod directional pattern that results from combining the figure-8 with the omnidirectional pattern from a whip. The sense of the incoming signal is usually determined by rotating the loop to cancel one of the lobes of the figure-8. In practical systems it is necessary to provide some phase- and amplitude-balancing between the two antennas.

To reduce the antenna effect that distorts the loop's directional pattern, and to obtain the best performance (in terms of detecting sharp nulls and uniform amplitude-peaks as the loop is rotated), the loop should be mounted within an *electrostatic shield*. That arrangement balances the loop by making sure that all parts of it will have the same capacitance to ground. That shield or cavity also protects the loop from the *induction field* created by nearby disturbances. The induction field refers to the electric and magnetic fields in the immediate vicinity of an antenna. Those fields decrease

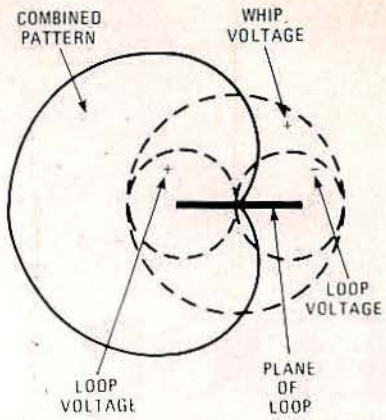


FIG. 2—A WHIP ANTENNA combined with a loop antenna can remove the ambiguity as to the sense of the oncoming wave.

rapidly in strength with distance, and the induction field is usually ignored (and the *radiation field* is all that is considered). However, wires and other metal objects near the loop can take energy from a passing wave and produce induction (and radiation) fields that can induce spurious voltages in the loop.

A shield over a loop antenna (one type of shielded loop is shown in Fig. 3) will not appreciably decrease the amount of magnetic flux that passes through (and links with) the loop when a wave goes by—as long as it does not form a complete (shorted to itself) turn. An insulated segment or gap is always left in the shield so that it does not become a shorted turn. Without the gap, the shield would form a shorted turn and it would reduce the magnetic field linking the loop so that no signal could be received by the internal wire(s). With the insulated segment or air gap, alternating currents can be induced in the metal shield (but no current will flow), and voltages will be induced in the internal wire(s). Some experimenters have wound loops inside slit *Hula-Hoops* and then shielded them by wrapping the outside with aluminum tape, leaving a gap in the tape at the top of the loop. Ferrite-core loops (which we will discuss shortly) are usually mounted axially in a trough or U-shaped channel (with the top and ends open to prevent a shorted turn) for electrostatic shielding.

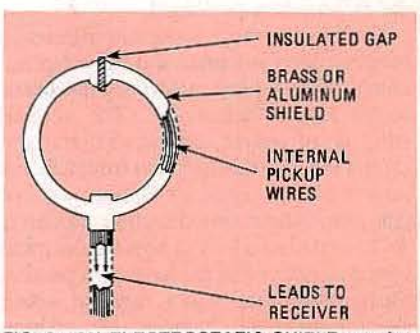


FIG. 3—AN ELECTROSTATIC SHIELD can improve the performance of a loop.

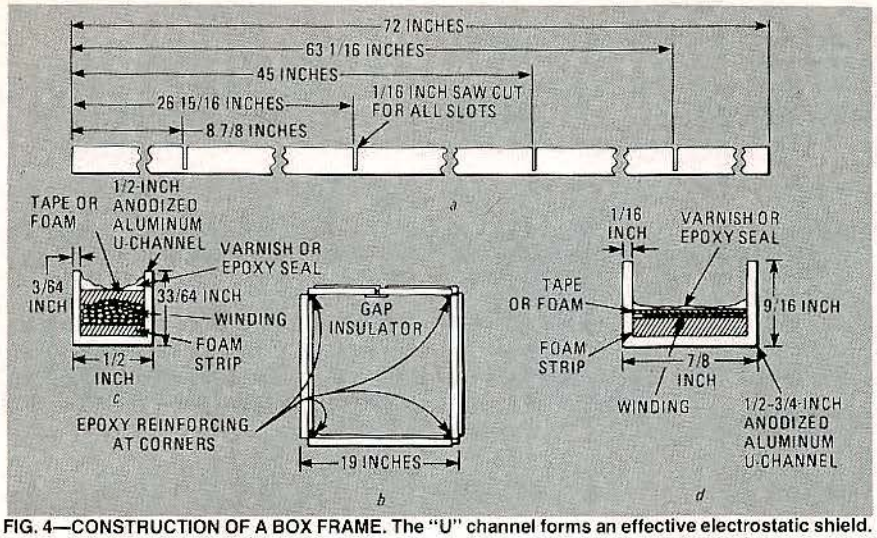


FIG. 4—CONSTRUCTION OF A BOX FRAME. The "U" channel forms an effective electrostatic shield.

A method for making a square box-frame loop is shown in Fig. 4. A long length of U-channel aluminum is formed into into a box frame by cutting slots into the side of the channel and then bending the material. A small gap with a plastic insulator in it is left at the top of the frame; the insulator holds it together and prevents it from forming a shorted loop. The coil winding is supported on plastic foam, just below the outer edges of the U-channel.

Winding loops

The distributed capacitance of the loop may, especially at low frequencies, cause the current to vary at different points on the loop and cause deviations in the directional pattern. A technique for reducing the distributed capacitance of the loop windings is to make the loop in a *mobius* form. A mobius loop is one where the coil is "twisted" so that (except at the start/finish point where the wires cross) all the "even-numbered" turns are adjacent to one another, with the same being true for the "odd-numbered" turns. The distributed capacitance of the mobius-type antenna shown in Fig. 5 is about one-half that of the antenna illustrated in Fig. 4—even though both contain the same number of turns. The mobius-wound antenna also has a wider bandwidth.

Effective length

When we discussed active-antenna systems, we frequently mentioned the *effective length* of an antenna (often referred to as *effective height*). We can also talk about the effective vertical length of a loop antenna. An approximation for computing the effective length, l_e, of loop antennas is:

$$l_e = \frac{2\pi\, nA\, \mu_r}{\lambda}$$

where λ = the wavelength in meters; n = the number of turns in the loop; A = the cross-sectional area of one turn in meters^2; μ_r = the effective permeability of the core material (= 1 for air core); and $\lambda = 3 \times 10^8$/frequency in Hz.

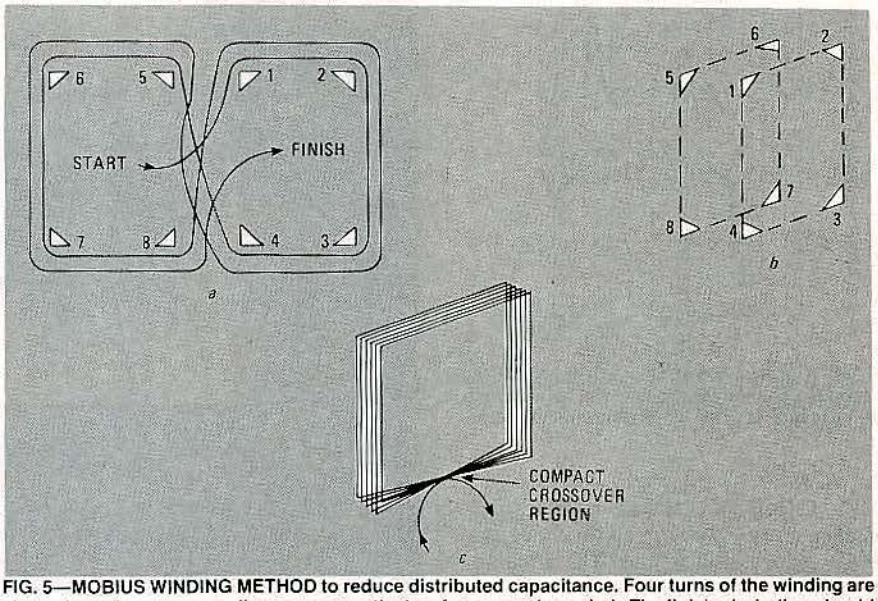


FIG. 5—MOBIUS WINDING METHOD to reduce distributed capacitance. Four turns of the winding are shown in *a*. The corresponding corners on the box frame are shown in *b*. The finished winding should look like *c*.

Small-size ferrite-core loop antennas

It is often useful to consider the smallest practical size of loop antenna that can be used, say for reception of signals such as those from WWVB at 60 kHz. Using a ferrite core increases the effective permeability of the core and, as you can see from equation 1, that increases the effective length. Ferrite cores are available commercially in several different permeability ranges. Figure 6 is a chart that illustrates the effective permeability of a ferrite rod compared to the bulk permeability of the ferrite material.

The whole idea of using a ferrite-rod core is to increase the magnetic flux density through the loop. For the maximum effect, you want to have as much of the core exposed to the winding as possible. Compact, multiple-layer coils in the center of a long core-rod are never as sensitive as a single-layer coil that covers almost the whole length of the rod. Unfortunately a long coil has a problem in that the distributed capacitance of the coil winding is quite high, and the Q of the long coil will not be as good as a coil with a better "shape-factor" (smaller length-to-diameter ratio). To maximize the coil's sensitivity to the magnetic field in space, the product of the number of turns and effective permeability of the rod should be as large a number as possible. From Fig. 6 it can be seen that the whole length of the rod should be used to maximize the effective permeability. Another factor to consider is the effect that the ferrite material used has on the Q of the coil. (At low frequencies, the maximum Q that can be obtained depends on the core material, its size, and the signal frequency.) Figure 7 describes the effect on Q for an 800 μ bulk-ferrite-material rod that measures ½

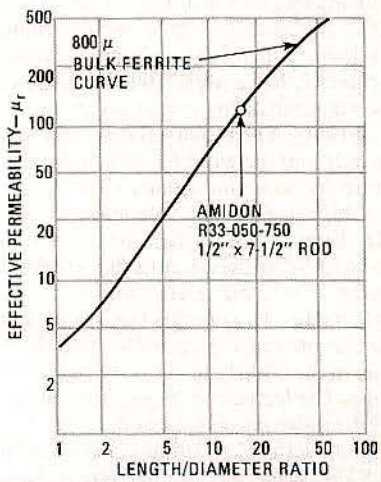


FIG. 6—THE PERMEABILITY of a ferrite rod does not depend only on the permeability of bulk ferrite, but also on its length and diameter.

TABLE 1—Loop Antenna Comparisons

Antenna	Square air frame	Square air frame	Small ferrite rod	Small ferrite rod	Small ferrite rod	Small ferrite rod
Materials	Aluminum channel 6 feet × ½ × ½ inch	Aluminum channel 6 feet × ½ × ¾ inch	Amidon 800 μ rod with trough shield	Amidon 800 μ rod with trough shield	Amidon 800 μ rod with trough shield	Amidon 800 μ rod with trough shield
Coil size	18½ × 18½ inches multiple layer	18½ × 18½ inches single layer	7½ × ½-inch solenoid	7½ × ½-inch solenoid	7½ × ½-inch solenoid	7½ × ½-inch solenoid
Turns wire	46, No. 28 stranded Teflon insulated	43, No. 28 enamel	555—270 left-hand 285 right-hand, No. 30 enamel	555—270 left-hand 285 right-hand, No. 30 enamel	555—270 left-hand 285 right-hand, No. 30 enamel	555—270 left-hand 285 right-hand, No. 30 enamel
Inductance	2.6 mH	2.5 mH	6.9 mH	6.9 mH	6.9 mH	6.9 mH
Capacitance	290 pF (distributed capacitance)	145 pF (distributed capacitance)	330 pF (distributed capacitance)	330 pF + 27 pF (distributed + external capitances)	330 pF + 680 pF (distributed + external capitances)	330 pF + 39000 pF (distributed + external capacitances)
Resonance	180 kHz	275 kHz	107 kHz	100 kHz	60 kHz	11 kHz
Effective Height	2.5 cm	2.5 cm	1 cm	1.4 cm	.88 cm	.16 cm

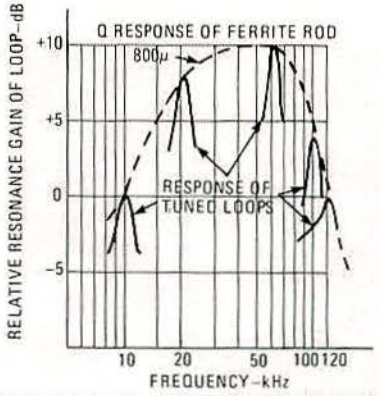


FIG. 7—THE RESPONSE OF A LOOP ANTENNA depends upon the response of the core as well as the response of the loops wound on the core.

FIG. 8—AN ACTIVE ferrite-core loop antenna in its trough shield.

× 7 × ½ inches. It also describes the antenna's response with and without external capacitances added. The winding properties of the ferrite-core loop are included in Table 1, and Fig. 8 shows the ferrite-core loop-antenna itself.

Comparing loops

The comparative properties of a ferrite-rod antenna and the two air core box frame loops (shown in Figs. 4 and 5) are shown in Table 1. The scramble-wound box loop, which is in a slightly smaller U-channel, has a higher winding capacitance that results in a resonant frequency of 180 kHz. The mobius flat-wound loop has only half the winding capacitance and almost the same inductance. That results in a higher resonant frequency of 275 kHz. Both of the air-core box loops are intended to be operated in the wideband mode with no external tuning-capacitance. The mobius box-frame loop has exceptionally deep nulls of 40 dB or more in the 60-kHz to 100-kHz frequency range. The ferrite-rod loop is intended for fixed-frequency use (tuned to 60 kHz with an external tuning-capacitor) for WWVB reception. Similar ferrite loops (where the loop coil and housing is different for each frequency band) that cover a wider frequency range are available commercially from several sources.

For an untuned box-loop, the upper-frequency limit is determined by the self-resonant frequency of the coil and its distributed capacitance. The effective length is greatest at that point, and it decreases by a factor of 10 or so at the 10-kHz low-frequency end. The box loop can also be tuned by placing a tuning capacitor in parallel with the loop coil. That will increase the Q, but a preamplifier with a higher input-impedance will be required. The best power transfer from the loop coil to the preamplifier is usually obtained when the loop impedance and the preamplifier input impedance of the preamplifier are in the same impedance range—which is not at highest Q. In designing loop antennas there is always a compromise to make between selectivity and sensitivity. An untuned loop with a rather broad self-resonant frequency peak (which is the case for the flat mobius-coil box-loop) provides the best sensitivity and also the deepest nulls of the antennas compared in Table 1.

Balanced loops

As we discussed previously, to obtain the best null-performance, loop antennas should be operated so that the capacitance between the antenna and electrostatic shield is the same at all points along the loop. With a single winding that's a problem, since one end of the winding has to be grounded in some way. A loop with a center-tapped winding is often used together with a preamp with a balanced input, but there is a better way of winding loops on long ferrite-rods that also reduces the inductance of the whole winding and results in a single-ended terminal for the loop.

The technique, developed by the U.S. Army Signal Corps many years ago, involves making right-hand- and left-hand-sense windings starting at the center of the core. The resulting loop, shown in Fig. 9, still has opposite-phase nulls off opposite

ends, but now has excellent electrostatic symmetry with respect to the trough shield. (The ferrite-core loop discussed earlier was a balanced loop.) The sensitivity of this coil is about the same as that of a coil wound in a single direction from one end to the other, but the inductance is reduced, resulting in a higher self-resonant frequency. The termination point in the center of the core practically eliminates induction-field noise-pickup, even with a single-ended preamplifier system. When winding a coil with a relatively large number of turns, it is advisable to check the winding for inductive balance because the ferrite core material may not be uniform from end to end. Another factor contributing to nonuniformity is that it is difficult to wind a perfectly spaced coil by hand. That is why the figures indicating the number of turns on each side of the antenna described in Table 1 are different.

To tune the balanced-loop coil arrangement shown in Fig. 9 to resonance at 60 kHz, a fixed capacitor of about 500 pF can be placed in parallel with a small variable capacitor of up to 350 pF (and the 330-pF distributed capacitance of the coils). That allows the total capacitance to be set to about 1000 pF—the capacitance required for resonance with the 6.89-mH inductance indicated in Fig. 7.

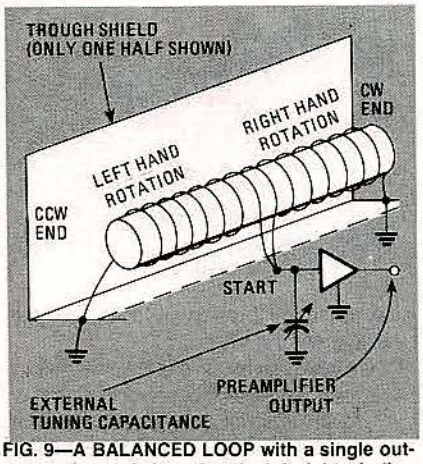


FIG. 9—A BALANCED LOOP with a single output can be made by using the left-right winding technique shown here.

Balun method

Another technique for making the capacitance of a single-winding loop symmetric with respect to the electrostatic shielding is to employ a toroidal balun (*BAL*anced-line to *UN*balanced-line) transformer between the loop winding and the preamplifier. That technique is illustrated in Fig. 10. The balun is used with the air-core box loops shown in Fig. 4, which have no center tap on the loop windings. The trifilar-wound transformer consists of about 30 turns of No. 30 insulated wire-wrap wire twisted 6 to 8 turns-per-inch and wound on an Amidon (12033 Ostego St., North Hollywood, CA 91607) FT82-75 high-permeability ferrite core. That makes the loop coil, which is a balanced source, look like an unbalanced source to the preamplifier. Baluns can also be used with ferrite-core antennas wound in a single-direction (instead of the right-left method of Fig. 9.)

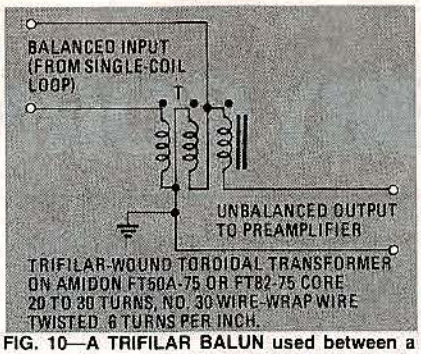


FIG. 10—A TRIFILAR BALUN used between a balanced loop and a preamplifier with an unbalanced input.

Loop antenna locations

Loop antennas are much less sensitive than small whips, but they have the advantage of having more selectivity as well as having directional null- and peaking- properties. It's a good idea to place a loop in the attic of a house well away from the electrical appliances and power lines, and to keep it away from major steel structural members (which, distort the local magnetic field).

High-gain preamplifier

When designing an active-whip antenna, we considered the whip to be a voltage source with a high internal impedance requiring current-amplification, and (to reduce attenuation due to a mismatch) we wanted the preamplifier also to have a high input-impedance. However, with a loop antenna, which is considered to be a low-impedance current source, we want a low-impedance voltage amplifier.

Almost all LF loop antennas will require a preamplifier with a voltage gain on the order of +30 dB. Low-noise performance is more important here than with whip antenna preamps because of the lower signal levels at the loop terminals. There is a great variety of circuits possible, but one of the simplest uses a power-FET or VMOS-FET like the one shown in Fig. 11. That preamp should be mounted directly at the terminals of the loop in a weatherproof shielded box or inside of a trough shield (with the balun transformer, if required). The output of the amplifier is fed (through a coaxial cable) back to the same receiver coupler that we used with the active antennas described in previous articles. The gate-bias voltage-divider trimmer potentiometer is adjusted so that the operating current of the receiver coupler is about 40 mA. The VMOS transistor used can be the Siliconix VN10KM. You can also use an ITT BS170—which has properties similar to

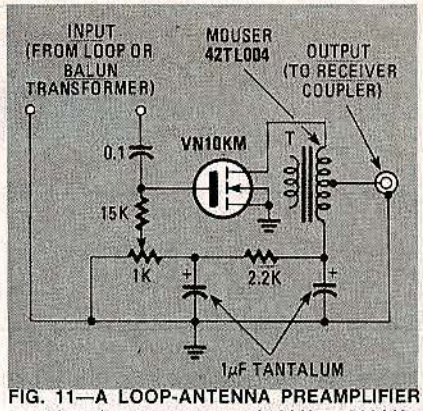


FIG. 11—A LOOP-ANTENNA PREAMPLIFIER used for a frequency range of 10 kHz to 500 kHz. The transformer is a audio-output transformer—200 ohms center-tapped: 8 ohms center-tapped. No connection is made to the secondary.

those of the VN10KM, but a different pinout. The series resistor for the gate bias, about 15,000 ohms, is chosen to approximately equal the reactance of the loop coil at the highest or cutoff operating-frequency. If a tuned loop coil with a higher Q is used, then the value of the resistor should be increased in value to 100,000 ohms or so. The output transformer can be the primary winding (about 200 or 600 ohms) of a subminiature or ultraminiature audio transformer. The secondary can be left open for operation up to the 500-kHz region. At higher frequencies, a bifilar toroid—such as the one wound on an Amidon FT50-75 core for the wideband active whip preamplifier—can be used as an output transformer. The preamplifier will have a voltage gain of about 30 dB when driving a 50-ohm load at the receiver coupler.

Bench testing loops

You can evaluate the resonant frequency of a small loop-antenna system by connecting a coupling coil and a 50-ohm load resistor in parallel as a termination at the end of a coaxial cable from a signal generator. For low-frequency testing (below 500 kHz) the coil can be a 1-mH pi-wound RF choke. The probe is brought very close to the loop under test to inject a small amount of signal by magnetic or inductive coupling. The output from the loop and/or a suitable preamplifier are then observed (either on an oscilloscope or a receiver) as the signal generator is tuned over the desired frequency range. The coupling sensitivity of both the probe coil and the loop will decrease at lower frequencies. This simple magnetic probe will allow you to obtain a good idea of the loop resonance and its general performance. You can also estimate the loop inductance by placing known capacitors in parallel with the antenna and then observing the response. The coil's distributed capacitance can be estimated by computing the difference between the resonant frequencies of the loop with and without the added tuning capacitance. **R-E**